PROGNOSTIC PROBLEMS ASSOCIATED WITH CUTOFF NEVADA LOWS

As Illustrated by the Case of October 23–24, 1956

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1 INTRODUCTION

This paper in general briefly discusses upper-level cutoff Lows that plunge into the Nevada area from the northwest during the fall months. In particular, it discusses the "explosive" surface and higher-altitude developments that occurred over North America between 0630 GMT, October 23 and 1230 GMT, October 24, 1956.

The presentation is confined primarily to the surface and 500-mb. levels and auxiliary charts, and all specific meteorological values or changes are for the 500-mb. level unless otherwise stated. Since surface tendencies and patterns at any given time almost entirely fail to foretell the depth and flow pattern around a deep developing Nevada storm 24 to 30 hours ahead, it is necessary to examine the upper flow and thermal field very closely to get an insight into the course of nature for the next day or so.

Whenever a vorticity cell at 500 mb. appears off the west coast of Canada or northwestern United States, the prognostic analyst is faced with the decision of either leaving the cell quasi-stationary in the same general area, or, in most cases, moving the center in one of the general directions of north, east, or south. When the current contours and isotherms up and down stream can be analyzed accurately, when the vorticity centers and ridges are well defined and conveniently spaced in a meridional flow pattern, and when the systems are moving uniformly the future direction of an impulse can usually be determined by subjective methods. Determining the rate of movement is more difficult. However, when there is strong zonal flow in which there are numerous minor impulses, the correct pattern at verification time is very elusive, especially if a big change in the zonal index occurs. The National Weather Analysis Center's (NWAC) prognostic analysts find that the Joint Numerical Weather Prediction Unit's (JNWP) numerical prognoses of the 500-mb. level have been very helpful in many situations where the index changes, where blocks develop or weaken, and where rate and direction of movement of systems are obscured to subjective methods.

Several plunging 500-mb. Lows complicated the weather picture during October 1956. During the first 3 or 4 days of the month a relatively weak quasi-stationary cutoff Low at 500 mb. was centered off the southern California coast. On the 4th and 5th a marked deepening occurred at more southerly latitudes near longitude 160° W., which caused the weak coastal impulse to move slowly eastward giving 0.50 to .70 inch of rain in the Santa Maria area. Twenty-four hour amounts of one to one and one-quarter inches were recorded at Bakersfield and Susanville on the 7th and 8th, respectively, associated with the movement of the closed Low into central Nevada by 1500 GMT, October 8.

In the meantime the deepening trough over the eastern Pacific had moved eastward and by 1500 GMT on the 8th an intense vorticity center with a closed 17,600-foot contour was centered 2° or 3° east of Ship Papa (50° N., 145° W.). By 0300 GMT on the 10th a deep trough had developed southward near latitude 170° W., and a sharp ridge was just west of Ship Papa, warming that station from −20° C. to −12° C. in 36 hours. Strong warm air advection toward Yakutat, Alaska, which warmed 10° C. in 12 hours, was maintaining the ridge between the two impulses. Thus at 0300 GMT on the 10th, the vorticity center about 5° longitude off Tatoosh was expected to move southeast. The speed of movement was very difficult to determine by subjective methods. There was no deep surface development with this situation but 24-hour rainfall amounts measured over an inch in southwestern and south-central Oregon.

Another good example of a plunging vorticity center is illustrated by the events occurring between 0300 GMT on the 26th and 1500 GMT on the 27th. A deep 500-mb. Low with a central height of 17,200 feet and temperature of −35° C. was centered near 51° N., 135° W. A sharp short-wave ridge to its west showed an 18,000-foot height value 25° longitude directly west of the cold Low and a 17,500-foot height at Barter Island. Any further building of heights to the north was halted due to very strong cold advection into the west side of the ridge and rapidly falling surface pressure already under the ridge, tending to tilt its axis northeastward toward Annette Island. In this case straight extrapolation of the cell of maximum cyclonic vorticity on the 500-mb. chart for 0300 GMT on the 25th would have placed the closed Low within 1° or 2° of the observed position on the chart for 1500 GMT on the 27th. The further history of this cell became very complicated and will not be discussed in this article.

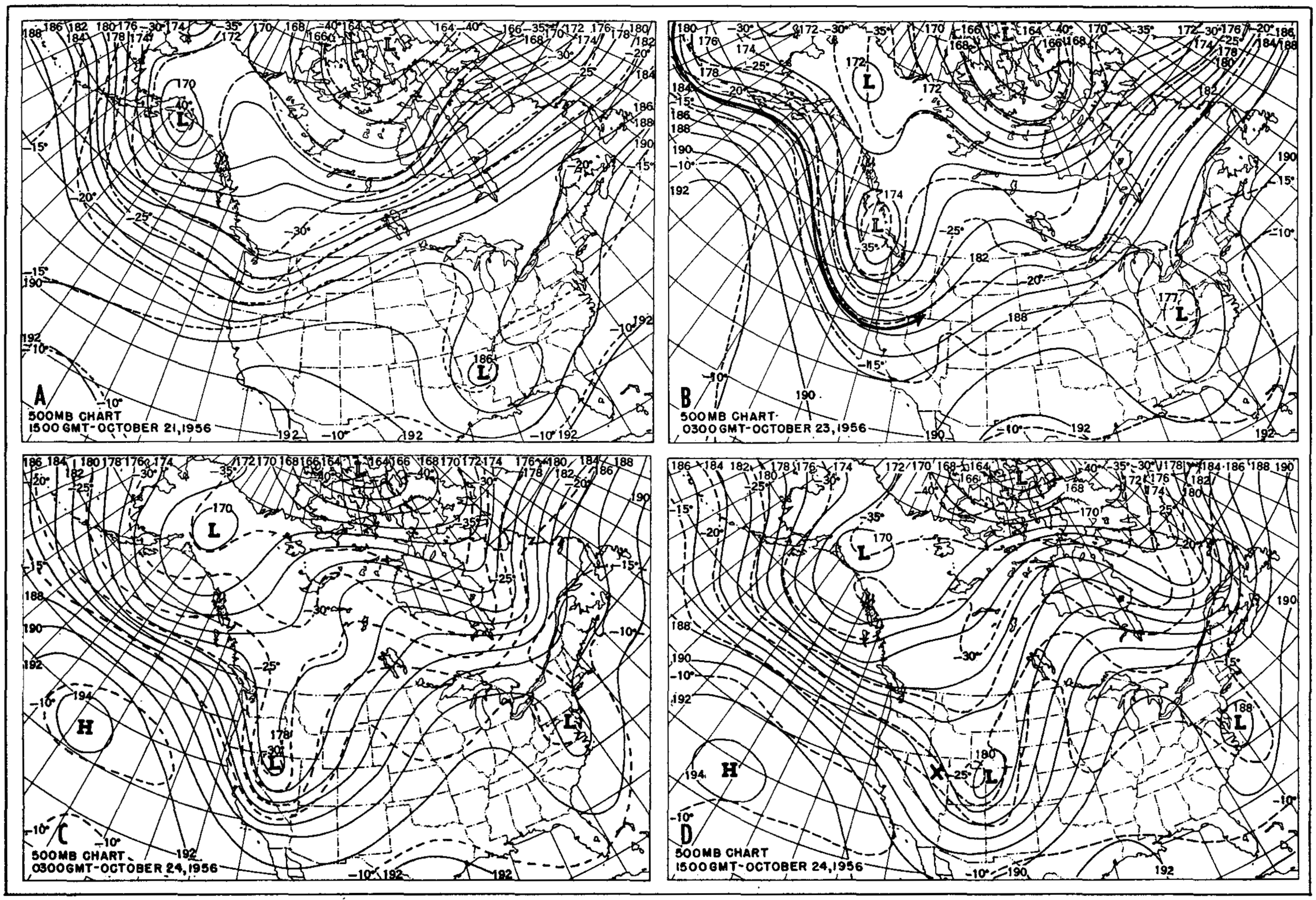


FIGURE 1.—500-mb. charts. (A) 36 hours before prognosis or 1500 GMT, October 21, 1956, (B) at forecast time or 0300 GMT, October 23, 1956, (C) 12 hours before verification or 0300 GMT, October 24, 1956, and (D) verification time or 1500 GMT, October 24, 1956. Extrapolated 36-hour position of the Low marked with an "X" on (D).

2. SUBJECTIVE PROGNOSIS OF THE NEVADA STORM OF OCTOBER 23–24

The primary topic to be discussed in this paper concerns the cold Low that plunged into the Nevada-Utah area during the period from 0300 GMT on the 23d to 1230 GMT on the 24th of October. This particular storm was chosen for study for the following reasons:

1. In retrospect, because the diagnosis of both its speed and depth by subjective means was more obvious compared to similar storms, it can be discussed with a reasonable amount of certainty.

2. The 30-hour surface prognostic chart prepared by one of the authors indicated the rather intense surface development, but placed the center much too far east.

3. The key to the rather "explosive" developments that occurred throughout the United States and Canada was the southeastward plunge of this cold Low.

Let us consider the subjective means that could be used to determine where to place the closed 500-mb. Low 36 hours after the time of prognosis. At 1500 GMT on the 21st (fig. 1A) the center under consideration was near 59° N., 149° W. with central height of 16,800 feet and temperature of −41° C. A significant vorticity maximum in the Oregon-Idaho area was destined to move rapidly east-northeastward, being controlled by the deep vortex over the Alaskan Gulf and the strong west-southwest flow south of the rather broad but potent cyclonic vorticity field west of the Hudson Bay area.

Thirty-six hours later at 0300 GMT on the 23d (fig. 1B), or at the time the forecast was made, the Alaskan Gulf Low had moved to the area of Port Hardy, British Columbia, with a central height of about 17,000 feet and temperature of −36° C. During the same period, the impulse from the Idaho area moved rapidly to Lake Superior and was associated with a weak surface Low south of Moosonee, Ontario. The very potent cyclonic vorticity maximum remained poised in the Churchill, Manitoba area. By examination of the contours and isotherms in figure 1B, and on the assumption that the Port Hardy Low would move eastward, little ridging could be expected to occur west of Hudson Bay to advect the vorticity south-

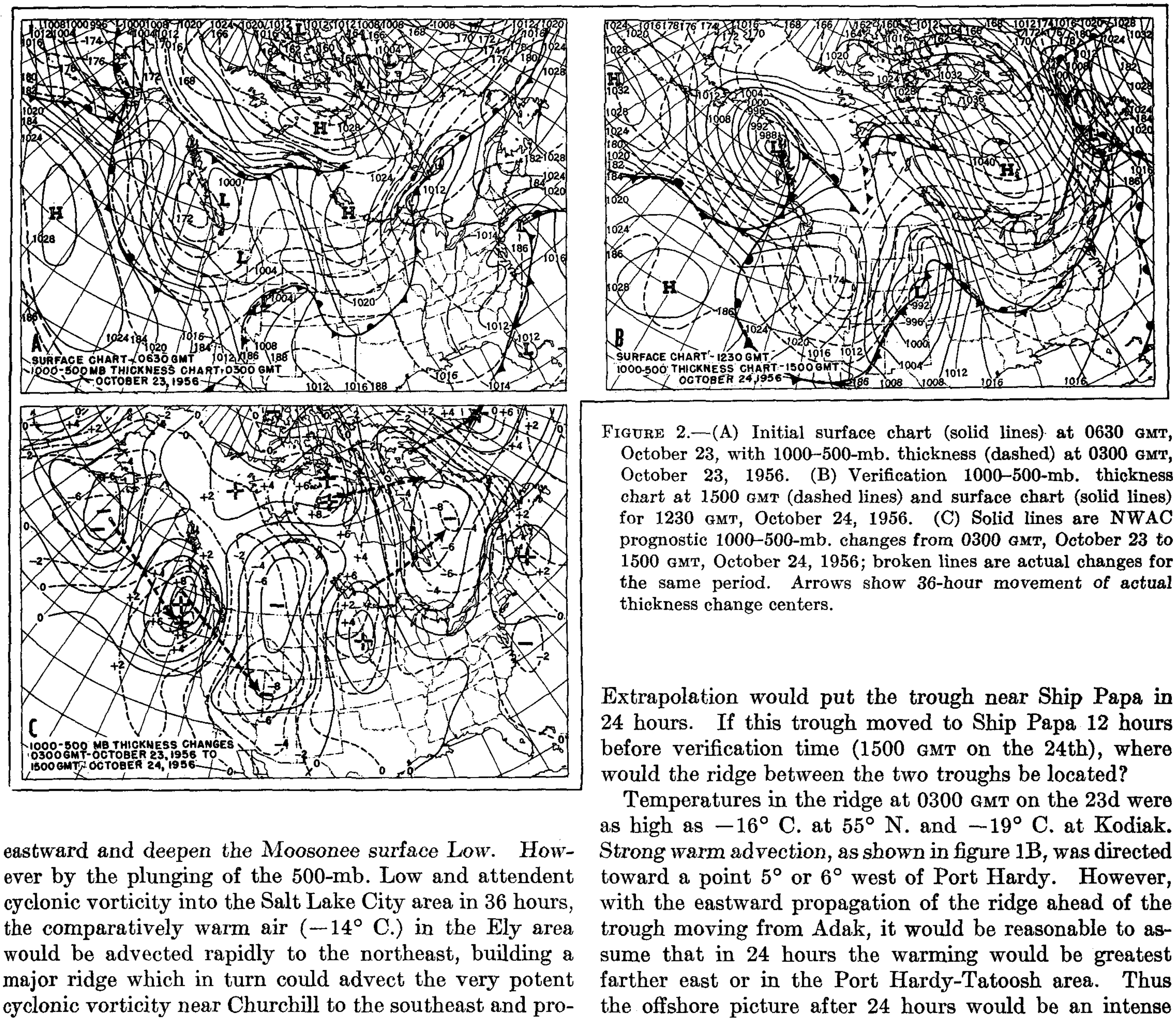
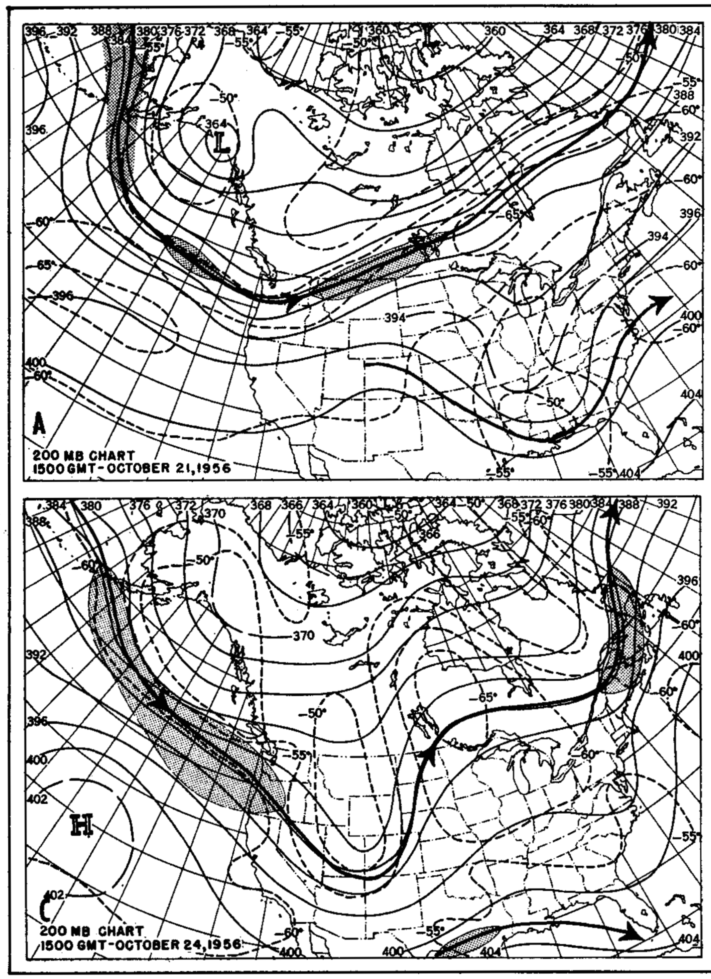


Figure 2.—(A) Initial surface chart (solid lines) at 0630 GMT, October 23, with 1000–500-mb. thickness (dashed) at 0300 GMT, October 23, 1956. (B) Verification 1000–500-mb. thickness chart at 1500 GMT (dashed lines) and surface chart (solid lines) for 1230 GMT, October 24, 1956. (C) Solid lines are NWAC prognostic 1000–500-mb. changes from 0300 GMT, October 23 to 1500 GMT, October 24, 1956; broken lines are actual changes for the same period. Arrows show 36-hour movement of actual thickness change centers.

eastward and deepen the Moosonee surface Low. However by the plunging of the 500-mb. Low and attendent cyclonic vorticity into the Salt Lake City area in 36 hours, the comparatively warm air (−14° C.) in the Ely area would be advected rapidly to the northeast, building a major ridge which in turn could advect the very potent cyclonic vorticity near Churchill to the southeast and produce intense surface deepening over the Canadian Atlantic coast.

From the positions shown by figures 1A and 1B, straight 36 hour extrapolation would have placed the 500-mb. low center near Elko, Nev., at verification time or 7° of longitude too far west as shown in figure 1D. Using this point as a tentative 36-hour prognostic position, let us explore the existing upper-air environment of the center at Port Hardy and attempt to find reasons for moving or not moving the extrapolated center. A quasi-stationary cold Low in the central Pacific, together with a well-defined short-wave trough of moderate amplitude that had moved into the Adak area, had already built a strong ridge at 155° W. Heights in the ridge were 19,200 feet at 45° N. and 17,400 feet 15° of latitude to the north giving a very strong jet with winds well over 100 knots as shown in figure 1B. Twelve hours prior to 0300 GMT on the 23d, the trough at Adak had moved roughly 12° of longitude. Extrapolation would put the trough near Ship Papa in 24 hours. If this trough moved to Ship Papa 12 hours before verification time (1500 GMT on the 24th), where would the ridge between the two troughs be located?

Temperatures in the ridge at 0300 GMT on the 23d were as high as −16° C. at 55° N. and −19° C. at Kodiak. Strong warm advection, as shown in figure 1B, was directed toward a point 5° or 6° west of Port Hardy. However, with the eastward propagation of the ridge ahead of the trough moving from Adak, it would be reasonable to assume that in 24 hours the warming would be greatest farther east or in the Port Hardy-Tatoosh area. Thus the offshore picture after 24 hours would be an intense cyclonic vorticity area near Ship Papa and also located north or north-northeast of the strong ridge that had developed 24 hours earlier. Continuing southerly circulation around the quasi-stationary cold Low in the central Pacific would tend to build heights even more to the south of Ship Papa. Thus height falls to the north and rises to the south would result in an intensifying vorticity field near Ship Papa. It should be mentioned here that neither was there any apparent deepening over the southern latitudes in the Ship Victor (31° N., 164° E.) area to move the cold mid-Pacific Low, nor was there any building high-amplitude ridge to the rear of the trough at Adak to produce enough deepening to "pick up" the closed Low and move it with the short wave. Along with the vorticity at Ship Papa there would be a sharp ridge of relatively warm air from the parent ridge in the Pacific and extending to the northeast toward the area evacuated by the plunging 500-mb. Low.



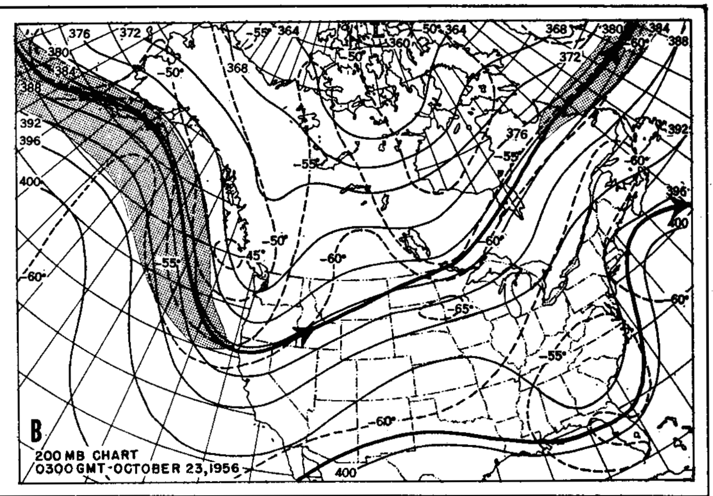


FIGURE 3.—200-mb. charts. (A) 1500 GMT, October 21, (B) 0300 GMT, October 23, and (C) 1500 GMT, October 24, 1956. Shading delineates winds of 100 kt. and over. Heavy arrows depict the jet stream.

The history of the movement and development of the trough and ridges discussed in the last two paragraphs, and the relative positions of the systems in figure 1B, suggest that a very reasonable path open to the Port Hardy Low, at least for the first 24 hours, would be along the line of proposed extrapolation. Twenty-four-hour trajectories would show a deepening trough inland over the Pacific Coast States. Since the warm air in the ridge could most easily be moved to the southeast as discussed before, there was little chance that a strong ridge could move in over southwestern Canada, thus plunging the Low due south or southwest. By pure extrapolation from the assumed offshore 24-hour prognosis, some of the intense cyclonic vorticity from the Ship Papa area would certainly be near the Washington coast 12 hours later at verification time. Allowing for some acceleration due to the rapid approach of the trough across the major ridge, 24-hour extrapolation would put the Low near southwestern Idaho. From the chart for 1500 GMT on the 22d, very careful extrapolation of the wind maximum along the jet would show the strongest winds to be inland and south of the assumed center. Thus at 0300 GMT on the 24th with the approach of the cyclonic vorticity to the Washington coast and the attendant propagation of the warm air in the ridge toward the assumed 24-hour position, and with the assumption that the wind maximum would move to the south of the impulse, the most likely direction of movement for the last 12 hours of the prognostic period would be eastward. Using the same rate of speed as before, the final 36-hour prognostic position would be reasonably close to the actual center as observed. Somewhat more objectively this could be inferred from Petterssen's [1] trough formula computations. Assuming the wind distribution to change little through the west coast trough, the gradually diminishing wavelength between this trough and the one upstream would require gradual acceleration of the speed of the first trough.

The 0300 GMT 500-mb. chart on the 23d showed falls of 700 feet in 36 hours in the Port Hardy area. Applying the same fall to the Grand Junction-Lander area would have given a very accurate estimation of heights around the center that verified 36 hours later.

Admittedly there has been an element of back-casting in the discussion so far. The authors are not aware of any computations or objective techniques that would determine the 36-hour movement of this type Low more accurately. Wilson's [2] grid method placed the center over northwestern Washington in 24 hours. Mean flow charts [3] prepared by NWAC moved the maximum vorticity associated with the Low to the east-northeast, and even the strictly objective JNWP thermotropic model moved the center to the east. Further discussion of the JNWP prognosis is made in section 4.

3. CHAIN REACTIONS DOWNSTREAM

In the remainder of the article, it will be accepted that the Low has moved to the position near Grand Junction as shown in figure 1D, and instead of discussing further prognosis, let us examine the rather dramatic changes

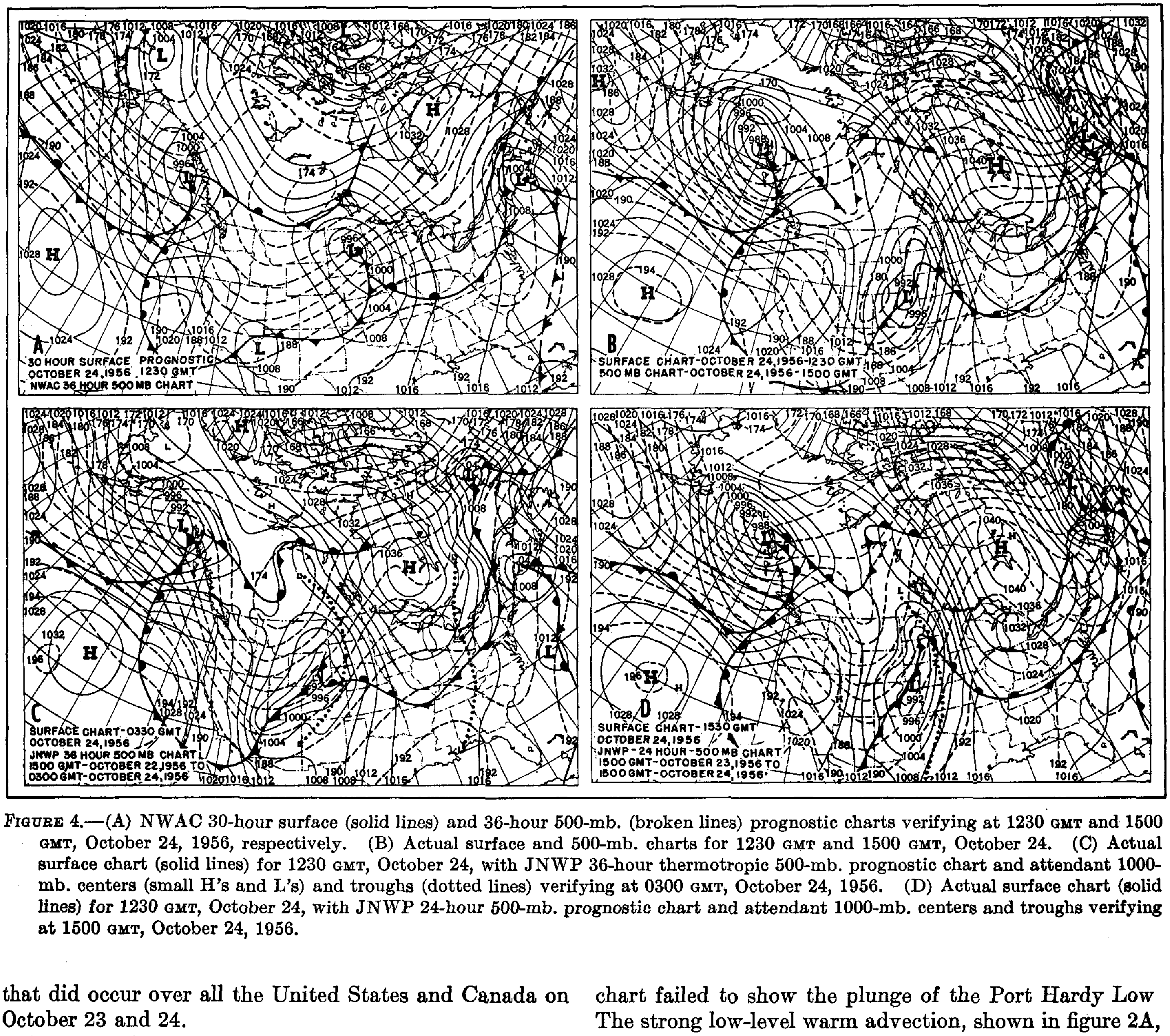


FIGURE 4.—(A) NWAC 30-hour surface (solid lines) and 36-hour 500-mb. (broken lines) prognostic charts verifying at 1230 GMT and 1500 GMT, October 24, 1956, respectively. (B) Actual surface and 500-mb. charts for 1230 GMT and 1500 GMT, October 24. (C) Actual surface chart (solid lines) for 1230 GMT, October 24, with JNWP 36-hour thermotropic 500-mb. prognostic chart and attendant 1000-mb. centers (small H's and L's) and troughs (dotted lines) verifying at 0300 GMT, October 24, 1956. (D) Actual surface chart (solid lines) for 1230 GMT, October 24, with JNWP 24-hour 500-mb. prognostic chart and attendant 1000-mb. centers and troughs verifying at 1500 GMT, October 24, 1956.

that did occur over all the United States and Canada on October 23 and 24.

At prognosis time (0630 GMT on October 23), the surface chart (fig. 2A) showed a filling Low of 998 mb. centered over southwestern Canada and two rather complex low pressure systems, one near Boise and the other southwest of Salt Lake City. Twelve-hour pressure falls of 12–14 mb. covered most of Idaho, Oregon, southeastern Washington, and the western half of Montana. In figure 2A, an initial injection of low-level cooling, as shown by isobaric cutting of the 1000–500-mb. thickness lines over northern California, was giving weak pressure rises, but the strongest cyclonic curvature and cold advection were still 10°–15° of longitude off the coast. The very low thickness values off Tatoosh plunged southeastward with the upper-level vorticity, giving a decrease of approximately 800 feet of thickness in the Ely area (fig. 2C). Most of this cooling was moved eastward by the NWAC prognostication since the 36-hour 500-mb. prognostic chart failed to show the plunge of the Port Hardy Low The strong low-level warm advection, shown in figure 2A, from Cheyenne north to the Canadian border, plus the new injection of warm air at all levels from the Las Vegas area ahead of the plunging upper Low, increased thicknesses 600–800 feet from Fargo north to Baker Lake (see fig. 2C). The resultant building of the ridge propagated the cold air and cyclonic vorticity poised in the Churchill area at 0300 GMT on the 23d to the southeast, accompanying the explosive deepening of the complex surface Low located near Moosonee at 0630 GMT on the 23d, and also contributed to the northward movement and deepening of the Low south of Nantucket (fig. 2B).

The rises in surface pressure in the Moosonee area and along the central Pacific coast were also spectacular. A High of 1028 mb. centered in the Winnipeg area moved to southern Hudson Bay and intensified to 1044 mb. The thickness changed very little in the High but 500-mb. heights increased about 400 feet allowing an increase of about 16 mb. in central pressure. The thickness at Medford changed very little in the 36-hour period but 500-mb. heights increased about 500 feet, allowing a pressure rise of about 20 mb.

Figure 1C, 12 hours before verification time, illustrates very clearly the thermal and dynamic processes taking place at 500 mb. with this type of development. The 500-mb. Low had plunged almost due south in the last 12 hours while the short-wave ridge that was due west of Ship Papa had rotated with its warm air to a northeastward orientation. The intense vorticity near Ship Papa had been propagated rapidly eastward and maximum winds around the Nevada trough had moved to the south of the impulse, indicating the eastward advance of maximum vorticity. The −15° C. isotherm had progressed northward from Nevada to southern Montana with strong warm advection directed toward Hudson Bay, continuing to build the major ridge. The very cold pool of air had already been advected southeastward from Hudson Bay, accompanying the further deepening and sharpening of the trough to the north of New England. Warm advection had increased over the Maritime Provinces and Labrador, giving more definition to the building ridge ahead of the plunging cold air and suggesting that further downstream reactions were yet to follow.

In the stratosphere and high troposphere these developments were rotating around a deep quasi-stationary 200-mb. Low centered near the Resolute Bay-Thule area. During the 36 hours before prognosis, a warm mass of stratospheric polar air moved southeastward to the Port Hardy area and tropical air was appearing as far north as the Lake Winnipeg area (figs. 3A and 3B) and starting to give definition to two distinct masses. As shown in figure 3C (the verification 200-mb. chart), the west coast mass of stratospheric air had plunged to the Great Falls-Grand Junction line and the next trough with its warm air had moved into the Alaskan Gulf. Cold tropical air had made little progress northward between the two systems as shown by the thermal pattern over Oregon and Washington; thus only a weakening ridge separated the two troughs, a condition favorable to eastward movement and weakening of the Rocky Mountain trough. A large area of −65° C. or colder air, as indicated by values at Churchill and International Falls, illustrates the magnitude of the northward thrust of tropical air over the building tropospheric ridge and surface High. The warm Hudson Bay pool of air had been propagated eastward and was well defined over northern Quebec.

The changes in height of the tropopause at the key stations of Port Hardy, Edmonton, Grand Junction, and Churchill were very significant during the 72-hour period from 1500 GMT on October 21 to 1500 GMT on October 24. During the 36 hours prior to prognosis time, the tropopause at Port Hardy sank 6,000 feet and warmed 10° C., at Edmonton it rose 11,000 feet and cooled 13° C., and at International Falls it lowered 6,000 feet and warmed 10° C. During the forecast period the tropopause at Grand Junction sank 12,000 feet and warmed 17° C. and at Churchill it rose 8,000 feet and cooled 9° C. Lowering of the tropopause is normally associated with tropospheric cold air advection with the greatest sinking near the core of the Low or area of maximum cyclonic vorticity. The lifting of the tropopause is associated with tropospheric warm air advection and anticyclogenesis. At 200 mb., the warming in the troughs and cooling in the ridges is due primarily to vertical motion associated with the sinking and lifting of the tropopause [4].

4. VERIFICATION

A comparison of figure 4A, the NWAC prognostic chart, and figure 4B, the verification chart, shows a serious error in prognosis in the Denver area. Although the large surface falls appearing over the northwestern States at 0630 GMT on October 23 were correctly moved to the Dakotas, the falls associated with the new injection of warm air stemming from the cutoff 500-mb. Low were moved too far east into Nebraska. The chain reaction of developments giving intense cyclogenesis in the Rocky Mountain States, intense anticyclogenesis over Hudson Bay, and explosive surface and upper-air deepening over the Maritime Provinces were indicated inadequately in the prognosis.

Figure 4C shows the last available JNWP 36-hour 500-mb. thermotropic prognosis and attendant 1000-mb. Highs, Lows, and troughs made 12 hours before the NWAC forecast. Fully aware of the value of the JNWP prognostic charts, the NWAC analyst failed to see any indication of a deepening Nevada Low. Comparison of the actual 0300 GMT surface chart and the JNWP prognosis shows obvious errors in the Grand Junction and Hudson Bay areas. Figure 4D is a copy of the numerical 24-hour 500-mb. thermotropic prognosis and attendant 1000-mb. centers and troughs made 12 hours after the NWAC forecast. Comparison with the actual 1500 GMT surface chart again indicates an error in the Denver area, but good verification in the James Bay area.

5. SPECIAL WEATHER PHENOMENA

On the 23d and 24th, strong winds occurred at the surface over a large area around the intense low center. Average wind speeds for this period as reported in the Local Climatological Data sheets were about double the monthly average for October at many stations from Nevada to Missouri and from Texas to the Dakotas. Severe duststorms were reported mainly in the warm sector of the Low. Precipitation with the Low was the first general precipitation over the Great Basin in several months. Amounts of ½ to over 1 inch occurred west of the Divide as far south as northern portions of California, Nevada, and Utah, and also in central Wyoming. Much of the precipitation was in the form of snow, particularly in the mountains. Snow also occurred in Colorado and northwestern Kansas. The strong cold northerly flow to the west of the Low brought temperatures of well below freezing to many stations in the Great Basin and Rocky Mountains. On the morning of the 24th, first frosts of the season were reported at several California stations. By the morning of the 25th, below freezing temperatures were reported as far south as Arizona and New Mexico. The strong southerly flow east of the Low caused well above normal temperatures over the Mississippi River Valley, particularly over the upper Mississippi Valley.

ACKNOWLEDGMENTS

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CORRECTION

MONTHLY WEATHER REVIEW, vol. 84, No. 9, p. 333: In column 1 of Extension to the Standard Atmosphere the name of the National Advisory Committee for Aeronautics was unintentionally omitted from the list of participating agencies.

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